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APOLLO 10 SEPARATION AND RECONTACT ANALYSIS SUMMARY DOCUMENT

Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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By Flight Studies Section
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May 15, 1969

MISSION PLANNING AND ANALYSIS DIVISION
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By Flight Studies Section

1.0 SUMMARY AND INTRODUCTION

The purpose of this report is to present a summary of separation and recontact analysis for the Apollo 10 mission. The purpose of these analyses was to determine the conditions that could produce potential recontact problems and to recommend procedures to alleviate such conditions. All separation and recontact analyses completed to date and applicable to the Apollo 10 mission are indexed and referenced in table I.

The nominal mission analyses are summarized in section 3 of this report. The following nominal separations were analyzed for the immediate, close-in, and eventual regions; and no potential recontact problems are present.

1. Transposition and docking (T&D)

2. CSM/LM ejection from the S-IVB

3. LM undock from the CSM

4. LM staging

5. LM jettison from the CSM

6. CM/SM separation

Summaries of separation and recontact analyses of abort conditions are presented in section 4. Potential or possible recontact problems are identified in table I.

2.0 SYMBOLS

AGS	abort guidance section
APS	ascent propulsion system
CM	command module
CSM	command/service module
DAP	digital autopilot
DOI	descent orbit insertion
DPS	descent propulsion system
DRPA	docking ring and probe adapter
LH_2	liquid hydrogen
LM	lunar module
LV	launch vehicle
RCS	reaction control system
S-IVB	third stage of Saturn V launch vehicle
SLA	spacecraft/LM adapter
SM	service module
SPS	service propulsion system
T&D	transposition and docking
TLC	translunar coast
TLI	translunar injection
TVC	thrust vector control
t_{ff}	time of free fall to entry interface

3.0 SEPARATION AND RECONTACT ANALYSIS OF NOMINAL PROCEDURES

3.1 Transposition and Docking

Nominal separation of the CSM from the SLA/LM/S-IVB is planned at TLI cutoff plus 25 minutes. The spacecraft will separate with 0.8 fps +X translation and then will begin maneuvers for T&D. These maneuvers are defined in reference 1 and indicate that there are no recontact problems.

3.2 CSM/LM Ejection from the S-IVB

The CSM/LM will be ejected from the S-IVB by four spring actuators at TLI cutoff plus 1.5 hours. At 5 seconds after ejection, the CSM will perform a 3-second -X RCS translation. The close-in separation displacements with and without the 3-second RCS translation and with 48 percent, 70 percent, and 90 percent spring efficiency are presented in reference 2. At 30 minutes after ejection, the spacecraft will perform a 3-second SPS evasive maneuver, pitched down 75° from the local horizontal. The relative motion for the SPS evasive maneuver and for the subsequent S-IVB dump sequence is presented in reference 3. Spacecraft gimbal angles for viewing the S-IVB at SPS ignition are presented in reference 4.

If the S-IVB LH_2 propulsive vent has failed open and cannot be closed prior to LM ejection, a contingency RCS maneuver at 1 to 5 minutes after ejection will be required to prevent recontact. It is recommended (ref. 5) that a 5-second +X RCS translation be performed prior to 5 minutes after ejection, with the CSM/LM alined in the SPS evasive maneuver attitude. This maneuver would be followed by the SPS evasive at 30 minutes after ejection.

3.3 LM Undocking from the CSM

The procedures and relative motion for LM undocking and the lunar rendezvous are presented in reference 1. The spacecraft separation burn occurs 30 minutes after LM undocking and at the 180° central angle prior to the LM DOI maneuver. No recontact problems are associated with undocking or separation maneuvers.

3.4 LM Staging

Nominal LM staging is planned for 10 minutes prior to the ascent stage insertion maneuver. The procedures and relative motion for nominal LM staging are presented in reference 1.

Long-term relative motion of the descent stage with respect to the CSM indicates that the descent stage orbit will phase with that of the CSM approximately 15 revolutions after staging. Real time monitoring of this problem is planned to determine if a CSM out-of-plane maneuver is required.

3.5 LM Jettison from the CSM

At 30 minutes prior to the APS burn to depletion, the CSM will jettison the LM. Then the CSM will maneuver above the LM and will perform a radially outward evasive maneuver of 2 fps which will place the CSM above and behind the LM at APS ignition. This procedure is defined in reference 1.

The LM jettison and CSM evasive maneuver procedure performed during earth orbit of the Apollo 9 mission was simulated for use during lunar orbit of the Apollo 10 mission. The relative motion is presented in figure 6 of appendix B in reference 6.

No recontact problems were identified with either of the above procedures.

3.6 CM/SM Separation

At t_{ff} = 17 minutes, the CSM will be in a pitched-down position so that the earth horizon will be alined along the hash mark on the command pilot's window. This mark is located 31.7° below the +X-axis of the CSM. At this time, an out-the-window IMU check is performed. From a t_{ff} = 17 minutes to a t_{ff} = 15 minutes, the CSM pitch attitude will be in inertial hold and a 45° yaw (+X-axis toward the north) maneuver will be performed in preparation for jettison of the SM. With the pitch in inertial hold and with the yaw maneuver added, the SM jettison will be performed out of plane by firing the four SM RCS -X jets to fuel depletion. After separation, the CM is yawed back in plane and is oriented to the entry attitude requirement.

An analysis of the separation distances between the CM and the SM based on the out-of-plane separation is presented in reference 7. In this analysis, the effect is evaluated of a minimum SM separation

ΔV being used and of the CM bank angle being achieved during entry in the direction of the trajectory of the SM. Delayed CM/SM separation times from the nominal planned time (t_{ff} = 15 min) were also analyzed to determine what effect the time of separation had on separation ranges. The results indicated that there are no recontacts between the CM and SM for a minimum separation ΔV and for separations which occur as late as 5 minutes prior to entry interface, regardless of the direction in which the CM banks at 1.5g.

Certain separation burn times ($\simeq$ 120 sec) cause the location of CM touchdown to be within the SM debris impact dispersion area, which could present a recontact possibility not only with the CM but also with the recovery forces. However, a burn to depletion is now planned and will eliminate this possibility of recontact with the SM debris. The nominal SM fuel depletion burn time capability for the Apollo 10 mission is approximately 300 seconds and eliminates all recontact problems.

An analysis of the CM/SM separation in the immediate recontact region indicates that for nominal conditions the interface forces which occur during the actual separation alone are sufficient to preclude recontact (ref. 8). Of the interface forces, the ordinance gas pressure impulse is most influential, the maximum value of which (290 lb/sec) is sufficient to insure no recontact.

4.0 SEPARATION AND RECONTACT ANALYSIS OF ABORT PROCEDURES

4.1 CSM/SLA/LV

4.1.1 Stable aborts during launch phase.- Separations of the CSM from the S-IVB for nontumbling, launch phase aborts (modes II, III, IV) were thoroughly analyzed for both close-in and long range recontact possibilities, and the results are presented in reference 9 for the Apollo 9 mission. In consideration of the similarity between the launch phase abort procedures and mass characteristics, only sample cases were analyzed for Apollo 10 for comparison with Apollo 9 relative motion. The results essentially duplicated those presented in reference 9 with all modes of aborts free from recontact (ref. 10). The only change from the abort procedures used for the Apollo 9 mission is that the mode IV SPS abort burn will be performed as soon as possible (within 90 sec) after S-IVB shutdown (ref. 11).

4.1.2 Stable aborts from orbit.- Separations of the CSM from the S-IVB while in an earth parking orbit can be defined by two different procedures. The prime procedure would involve manual control of the booster by the crew, orientation to a heads-up horizon monitor (rearward) attitude, and separation with 5 fps ΔV. The alternate procedure would mean separation of the CSM with a 5-fps burn at the S-IVB attitude; this burn would be followed by 30 seconds of coast and orientation followed by a 30-second RCS four-jet burn in the rearward horizon monitor, heads-up attitude.

Detailed analyses were conducted for the Apollo 9 mission and are presented in reference 12. Check cases were simulated for the Apollo 10 mission with the relative motion virtually unchanged. Concurrence that the same maneuver presents no recontact problems for the Apollo 10 mission is published in reference 10; representative relative motion plots are presented in reference 12.

4.1.3 Impending explosions.- During the time interval from lift-off until CSM/S-IVB separation, the crew is able to monitor directly the fuel tank pressures on the booster. A sensory device in the CM will warn the crew of an impending booster explosion if the tank pressures should exceed an acceptable pressure limit. This device will allow the crew a minimum of 200 seconds warning time prior to the explosion in which time the crew must effect CSM/S-IVB separation and attain a separation distance between the vehicles of 7080 feet. This distance results in an impact probability of 1 in 100 000 with debris generated by the booster explosion. To insure this distance prior to warning plus 200 seconds, the sequence of events presented in reference 13 is recommended. This procedure involves a 4-second SPS burn initiated at warning plus 6 seconds. The 7080-foot distance will be achieved at warning plus 182 seconds.

The second type explosion examined involves the LM descent stage. However, the problem area is not sufficiently defined to allow a separation sequence to be defined. The necessary studies have not been performed to allow definition of a warning time or safe separation distance. Therefore, the extent of the separation analysis is contained in reference 14 which examines the effectiveness of each available propulsion system on the CSM or LM ascent stage as a function of system burn time. Until certain ground rules and constraints are defined, no further analyses can be conducted.

4.1.4 CSM/SLA panels separation, launch phase and orbital phase aborts.- Relative motion of the four SLA panels with respect to the spacecraft for aborts that occur during the launch phase or orbital phase is presented in reference 15. Although this analysis was performed for the Apollo 9 mission, check cases have confirmed that it is applicable to the Apollo 10 mission. The results of this analysis indicate that there are no recontact problems for any launch or orbital phase aborts with the exception of the first 30 seconds of the SPS retrograde mode III region.

4.1.5 Nonstable, tumbling launch phase and orbital phase aborts.- The analysis to identify possible recontact situations during launch aborts has been divided into two study areas: (1) immediate recontact - recontact occurs during the first 30 seconds after CSM separation from the LV and the jettisoned panels, and (2) close-in recontact - recontact occurs during certain launch abort modes which results from a procedural SPS burn that occurs approximately 2 minutes after CSM separation from the LM and SLA panels. Results from presently available analyses were shown to be applicable to Apollo 10 (ref. 16).

The specific results of the launch abort immediate recontact study are as follows.

a. CSM separation from a nontumbling LV presents no problem of immediate recontact.

b. CSM separation from a tumbling LV presents no problem of immediate recontact when the RCS/SCS is used for rate damping.

c. CSM separation from a tumbling LV can result in immediate recontact with the S-IVB or with a SLA panel when the TVC/SCS is used for rate damping.

4.1.6 TLI and TLC 90-minute aborts.- The current procedures for separation from the S-IVB and maneuvers to the TLI or TLC abort burn position and attitude are defined in reference 17. At 1 minute after separation from the S-IVB, the spacecraft will perform an 8- to 10-second RCS translation radially upward, along the positive radius vector. Then the spacecraft will orient to the abort burn attitude, and SPS ignition will occur at 10 minutes for a TLI abort or approximately 90 minutes after TLI cutoff for the 90-minute TLC abort. These procedures have been simulated, and no recontact problems with the S-IVB or the SLA panels have been identified.

4.2 CSM/LM Ejection from the S-IVB

Analysis of CSM/LM ejection for immediate recontact problems was investigated for Apollo 10 (ref. 18). Worst-case separation conditions were combined with single subsystem failures to determine conditions where recontact would occur. CSM control options (including no control) and a 3-second -X RCS burn 5 seconds after ejection were also considered. Mass properties corresponding to Apollo 10 nominal conditions were simulated. Lighter and heavier than nominal Apollo 10 S-IVB weights were considered in the Apollo 9 analysis.

The results of this analysis indicate that recontact during LM ejection will not occur for the Apollo 10 mission, with or without CSM/RCS -X thrusting during ejection. Unlike Apollo 9, recontact does not occur during ejection for a single spring or jet failure. For Apollo 9, the S-IVB was heavier, and a spring or jet failure would result in recontact. However, for a partial or no TLI burn on Apollo 10, when the S-IVB weight becomes near equal or heavier than the Apollo 9 nominal S-IVB weight, the same failures could result in a recontact problem.

As for Apollo 9, an S-IVB APS failure that results in transverse rates can cause recontact problems. For an inactive CSM control system during ejection, rates of more than ±0.6 deg/sec will cause recontact for 48 percent spring efficiencies. If the CSM/SCS is active, transverse rates of up to ±3.5 deg/sec can be tolerated during ejection.

The conclusions are that for LM ejection on the nominal Apollo 10 mission, no recontact will occur, with or without CSM -X RCS thrusting. An RCS jet failure during CSM -X thrusting will not cause recontact, unless a partial or no TLI burn results in a heavier S-IVB at ejection. The only subsystem failure identified which could cause recontact is a failure of the S-IVB APS to maintain attitude control during ejection.

4.3 LM Undocking from the CSM and LM Jettison

The immediate separation and recontact problems that could be associated with LM undocking and jettison from the CSM have been analyzed (ref. 19). Factors considered in the analysis include the CSM and LM control systems options, vehicle mass configurations, the worst-case combination of separation pitch and yaw rates, docking tunnel pressure variances, and RCS jet failures.

Based on the analysis presented in reference 19, conclusions are that undocking or jettison of the LM will not result in immediate recontact problems for the Apollo 10 mission. The undocking and jettison impulses alone are sufficient to prevent recontact for tumbling conditions at separation (rates = 0 ±10 deg/sec) unless a CSM/RCS jet fails and induces a net +X translation to the CSM.

4.4 LM Staging

Immediate recontact problems associated with the LM/RCS and inadvertent staging under nonnominal and alternate mission conditions were investigated (ref. 20). The problems included were the following: (1) a comparison of the AGS and DAP control options, (2) staging under DAP control for alternate mission conditions, docked and undocked configurations, (3) the effects of RCS jet failures and structural stiffness variation, and (4) inadvertent staging of a docked or undocked LM. Seven control options of the LM DAP and five control options of the CES were analyzed, and limiting pitch-yaw rates were defined for each option under which LM staging could be accomplished without immediate recontact (ref. 20).

The conclusions of the LM staging analysis were as follows.

a. Nominal LM staging under AGS control can best be performed with narrow deadband limits. Immediate recontact will not occur with either wide or narrow deadband for rates under 6 deg/sec.

b. For rates greater than 6 deg/sec, staging can best be accomplished with a 1-second RCS +X direct ullage maneuver without LM DAP or AGS control.

c. Mass variations that simulate alternate mission conditions produced no significant effect on nominal recontact rate limits. Staging in a docked or undocked configuration can be accomplished without recontact under LM DAP control. If rates are greater than 6 deg/sec and if the LM is undocked, then item b above is applicable.

d. When a staging relay failure might cause the LM to stage inadvertently while in an undocked configuration, the LM DAP must be operating in the narrow deadband option to prevent recontact. If the LM is in a docked configuration, inadvertent staging will not cause recontact when the control modes are the CSM DAP, LM DAP, or no control.

4.5 CM/SM and CM/DRPA Separation

The results are presented in this section of analyses performed for CM/SM and CM/DRPA separations after mode II, mode III, orbital, TLI, and TLC aborts. Immediate and eventual recontact situations were considered. No recontact problems were identified between the CM and SM for mode II, mode III, or orbital aborts. The possibility exists of an eventual SM recontact with the CM for TLI and TLC abort cases when the SM weight at separation is less than 16 000 pounds (TLC aborts at g.e.t.'s of 7 hrs and 47 hrs result in weights of less than 16 000 lb), when the jettison ΔV is smaller than 18 fps, and when the CM banks in the same direction as the jettisoned SM. If the SM weight and ΔV should be less than the above values, recontact can still be avoided by banking the CM (at 1.5g) in the opposite direction of the path of the SM.

The only area of recontact between the CM and DRPA occurs in the mode II abort region when the CSM holds inertially the attitude it had at abort initiation and the DRPA is jettisoned inplane at this attitude. Recontact can be eliminated for this separation attitude by jettison of the DRPA out of plane. If out-of-plane separation of the DRPA cannot be performed, safe separation distances between the CM and DRPA can be achieved by orientation of the CSM to the CM entry attitude followed by jettison of the DRPA at the same time that the SM is separated.

4.5.1 Immediate recontact, nonnominal conditions.- The results of reference 8 indicate that the interface forces produced during the actual separation insure no immediate recontact. No recontacts were noted for either stable or tumbling configurations.

4.5.2 Mode II.- The SM and DRPA would have to be jettisoned prior to entry interface if a mode II abort should occur. Planned procedures call for SM jettison out of plane if $t_{ff} > 120$ seconds.

The results of reference 21 indicate that simultaneous out-of-plane separation of the SM and DRPA will preclude any recontact between these bodies and the CM. For inplane separations, no recontacts between the CM and SM were discovered when the CSM held inertially the attitude it had at the time of abort initiation. However, jettison of the DRPA inplane at this attitude caused a recontact situation. Jettison at this attitude resulted in the DRPA flying in front of and above the CM initially. At the CM altitude of approximately 300 000 feet, the DRPA started to drop below and behind the CM. The minimum separation ranges for early, mid-, and late mode II aborts were 143 feet, 148 feet, and 646 feet, respectively. All these ranges were considered to be recontacts because of possible deviations in the DRPA aerodynamics during atmospheric entry.

Recontact between the CM and DRPA or between the CM and SM was not observed when both the SM and DRPA were jettisoned inplane at the CM entry attitude. Therefore, it was recommended that if out-of-plane separation could not be performed, the CSM be oriented to the CM entry attitude and, when this attitude is reached, the SM and DRPA be jettisoned.

4.5.3 Mode III.- After the mode III SPS burn, it is planned to perform the CM/SM separation out of plane if $t_{ff} > 120$ seconds to insure no recontact between the CM and SM. The study presented in reference 22 was performed to determine if there would be any recontacts between the CM/SM and the CM/DRPA for separations inplane and to determine the most desirable time to jettison the DRPA. All separations were assumed to occur in the deorbit burn attitude.

The conclusion of reference 22 was that jettison of the SM and DRPA out of plane will eliminate recontact. The most optimum time to jettison the DRPA is at the time of CM/SM separation for both inplane and out-of-plane separations; therefore, this time was recommended. If out-of-plane separation could not be performed, there still would be no recontact if separation were performed in the deorbit attitude.

4.5.4 Orbital aborts.- A study (ref. 23) was performed to determine the separation distances between the CM/SM and the CM/DRPA for an orbital abort case for which an immediate return to earth is required. Separation of both the SM and DRPA was performed at the deorbit attitude. The study recommends that DRPA jettison be performed out-of-plane at the time of CM/SM separation because there is no recontact problem when the DRPA is jettisoned at the time of CM/SM separation.

4.5.5 TLI and TLC aborts.- Analyses are presented in reference 7 of the TLI and TLC abort cases based on separation at entry interface minus 15 minutes (using same procedures as used for nominal entry), based on a minimum SM separation ΔV (out of plane), and based on CM entries which require the CM to bank toward the path of the SM. No areas of recontact between the SM and CM were found except for TLC aborts at 7 hours and 47 hours g.e.t. The SM weights at CM/SM separation for these aborts are less than 16 000 pounds. These SM weights associated with ΔV's of 18 fps or smaller could produce a recontact between the CM and SM. This recontact situation can be avoided by banking the CM at 1.5g in the opposite direction from the out-of-plane jettison of the SM.

The results of reference 24 indicate that there are no recontacts between the CM and DRPA when the DRPA is jettisoned out of plane at the time of CM/SM separation, even when the CM banks in the same direction that the DRPA is jettisoned and when separation occurs as late as 5 minutes prior to entry interface.

TABLE I.- SUMMARY OF SEPARATION AND RECONTACT ANALYSIS

Separation	Recontact problems	Document section	Reference	Comments
(a) Nominal mission				
T & D	No	3.1	1	
LM ejection	No	3.2	3	
LM undocking	No	3.3	1	
LM staging	No	3.4	1	DPS orbit phasing with that of the CSM is possible; CSM out-of-plane maneuver may be required.
LM jettison	No	3.5	1,6	
CM/SM SEP	No	3.6	7	SM burn to depletion planned to eliminate recontact problems
(b) Nonnominal mission				
Stable aborts				
Launch phase	No	4.1.1	13,14	
Orbital phase	No	4.1.1	16	
Impending explosions	No	4.1.3	17,18	
CSM/SLA panels (launch and orbital phase aborts)	Yes	4.1.4	19	Possibility of recontact with a SLA panel during early mode III region SPS aborts
Tumbling launch and orbital phase aborts	Yes	4.1.5	22	After SPS abort ignition, recontact is possible with the S-IVB or the SLA panels
TLI and TLC aborts	No	4.1.6	20	
LM ejection	Yes	4.2	25	Tumbling LV at ejection could result in recontact
LM undocking	No	4.3	24	
LM jettison	No	4.3	24	
LM staging	No	4.4	23	For high rates (>6 deg/sec) or inadvertent staging, procedures are recommended
CM/SM SEP				
Immediate	No	4.5.1	12	
Mode II	No	4.5.2	8	
Mode III	No	4.5.3	9	
Orbital	No	4.5.4	10	
TLI and TLC	Yes	4.5.5	7	

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